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SYSTEM CAPABILITIES AND DEVELOPMENT SCHEDULE OF THE DEEP SPACE INSTRUMENTATION FACILITY 1961 - 1966

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In collaboration with the Engineers
of the Telecommunications Division

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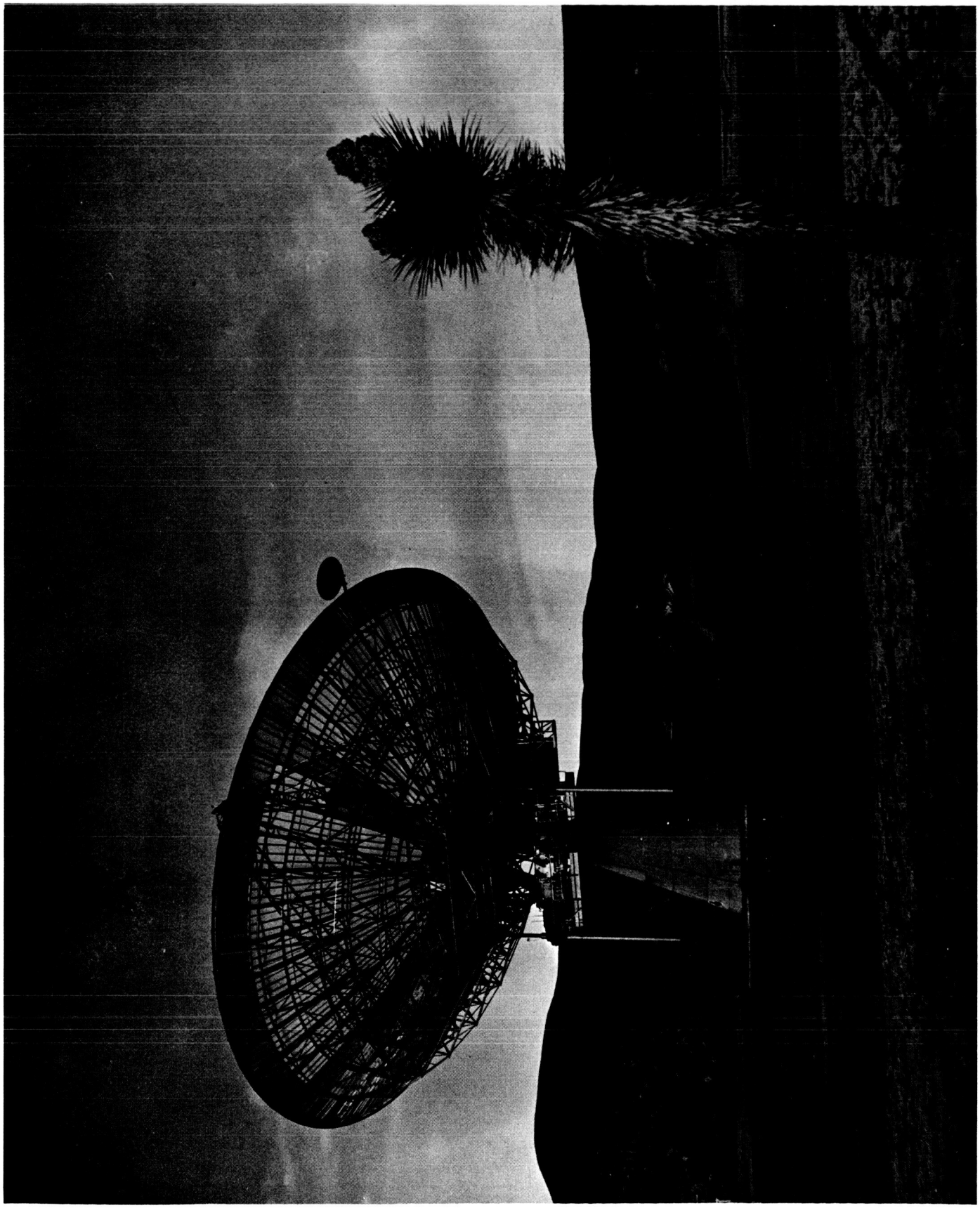

FOREWORD

The purpose of this publication is to familiarize those agencies anticipating use of the Deep Space Instrumentation Facility (DSIF) with both its existing capabilities and those programmed in the immediate future. In general, the DSIF capability is matched to the requirements of the missions of the Jet Propulsion Laboratory in its exploration of outer space; however, the capability can be adapted to the needs of other programs without undue difficulty.

The capabilities shown in this Memorandum fall into three categories: existing facilities, authorized and funded projects, and proposed but not funded facilities.

N. A. Renzetti, Deputy
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I. INTRODUCTION

An integral requirement in the conduct of scientific investigations of outer space is the establishment of a precision tracking and communications system capable of providing command, telemetering, and positional tracking of the space probe. The Deep Space Instrumentation Facility (DSIF) has been established to satisfy this requirement in lunar and planetary programs for which the Jet Propulsion Laboratory (JPL) has been assigned responsibility by the National Aeronautics and Space Administration (NASA). The DSIF is primarily intended for use in experiments conducted at lunar distances and beyond; however, certain experiments in cislunar space may utilize the DSIF stations when schedules permit.

The DSIF is comprised of three Deep Space Stations (DSS), a mobile station, and the intersite communication links providing for transfer of data and for administration of operations by JPL. A second mobile station is planned for operational use in 1963. The DSS's are presently equipped with 85-ft-diameter reflectors, and can track at angular rates to 1 deg/sec. These large reflectors are used mainly for deep-space experiments. The mobile station is equipped with a 10-ft diameter reflector, and can track at angular rates to 10 deg/sec. The mobile station is used mainly for command, telemetering, and tracking of space probes from injection to about 10,000-mi altitude.

The design philosophy of the DSIF is to provide a precision radio-tracking system which measures two angles, radial velocity and range, and then to utilize this tracking system to send radio commands and to receive radio telemetry in an efficient and reliable manner. The DSIF is scheduled to undergo long-term

improvement and modernization consistent with the state of the art and spacecraft requirements. One of the basic design requirements of the DSIF is that it be possible to incorporate these improvements quickly, easily, and economically.

NASA is the cognizant United States agency responsible for the DSIF. JPL, of the California Institute of Technology, is under contract to NASA for the research, development, and fabrication of the DDS's and mobile stations for the technical coordination and liaison necessary to establish and operate the DSIF throughout the world. Overseas DSS's at Woomera, Australia, and Johannesburg, South Africa, will be operated by personnel provided by cooperating agencies in the respective countries. The Goldstone station and the mobile stations will be operated by United States personnel.

The Goldstone station, in addition to its participation as a member of the DSIF, is utilized for extensive research and development in space tracking and communications. In most cases, new equipment will be installed and tested at Goldstone before it is integrated into the DSIF.

II. STATION GEOMETRY

The three DSS's are spaced at approximately equal intervals of longitude around the Earth and are located as shown in Table 1.

Table 1. Deep Space Station locations

DDS location	Code	Geodetic latitude	Longitude
Goldstone, Calif., U.S.A.	GS	35.389°N	116.848°W
Woomera, Australia	W	31.382°S	136.886°E
Johannesburg, South Africa	J	25.891°S	27.675°E

The mobile stations will, in most cases, be located so as to cover the injection point and immediate post-injection trajectory of the spacecraft, which tend at the present time to be centered in the Southern Hemisphere. Typical DSS and mobile station installations are shown in Fig. 1 and 2.

The loci of subvehicle points, with 5-deg horizon mask angles at Woomera and Johannesburg, and the natural mask at Goldstone, are shown in Fig. 3. This figure indicates the field of view of each DSS as a function of vehicle altitude, as well as showing the region of overlapping coverage. The field of view of mobile stations is somewhat less restricted because they are normally emplaced on elevated locations.

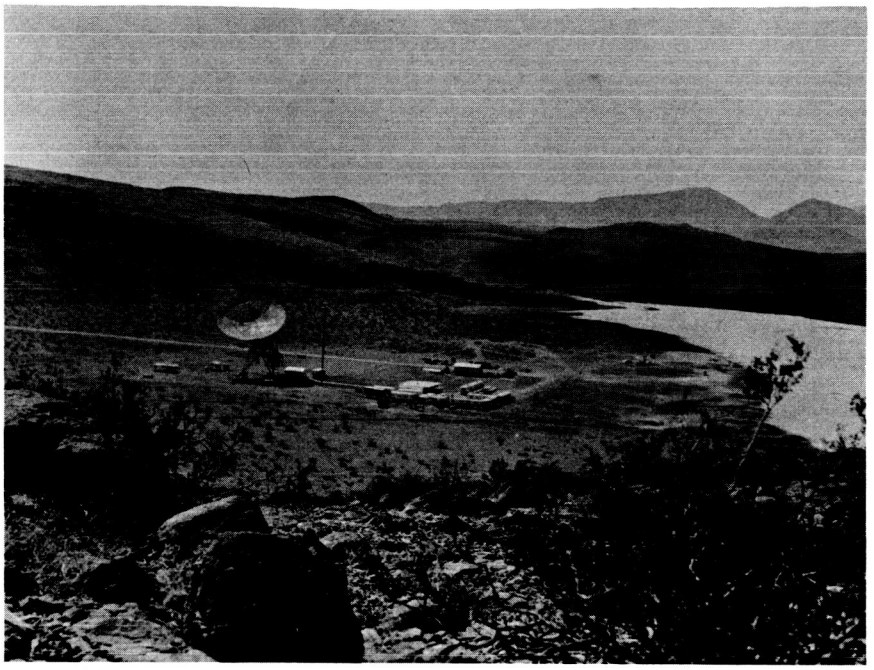


Fig. 1. Typical Deep Space Station
(Goldstone receiver site)

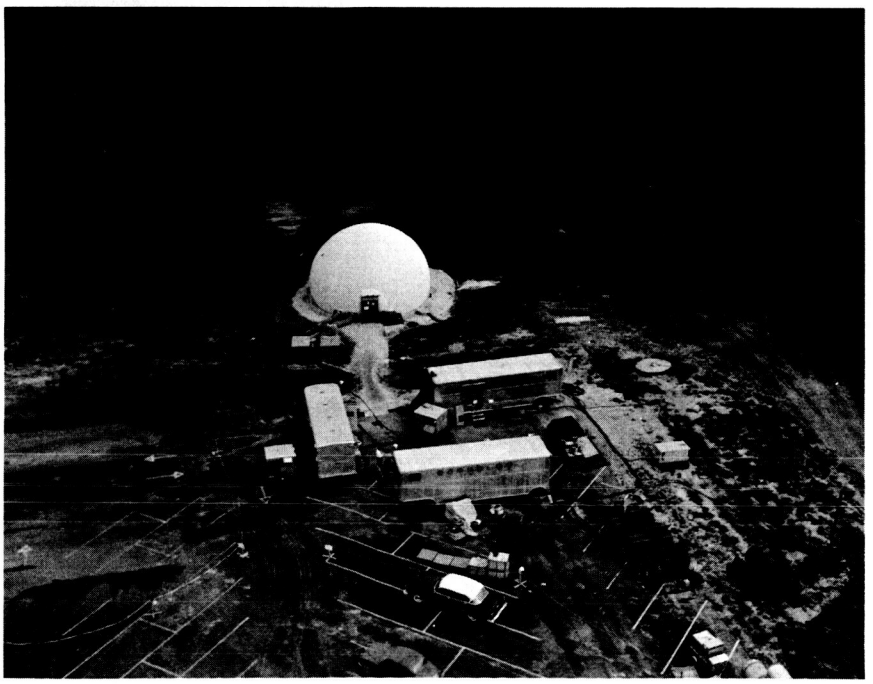


Fig. 2. Typical mobile station

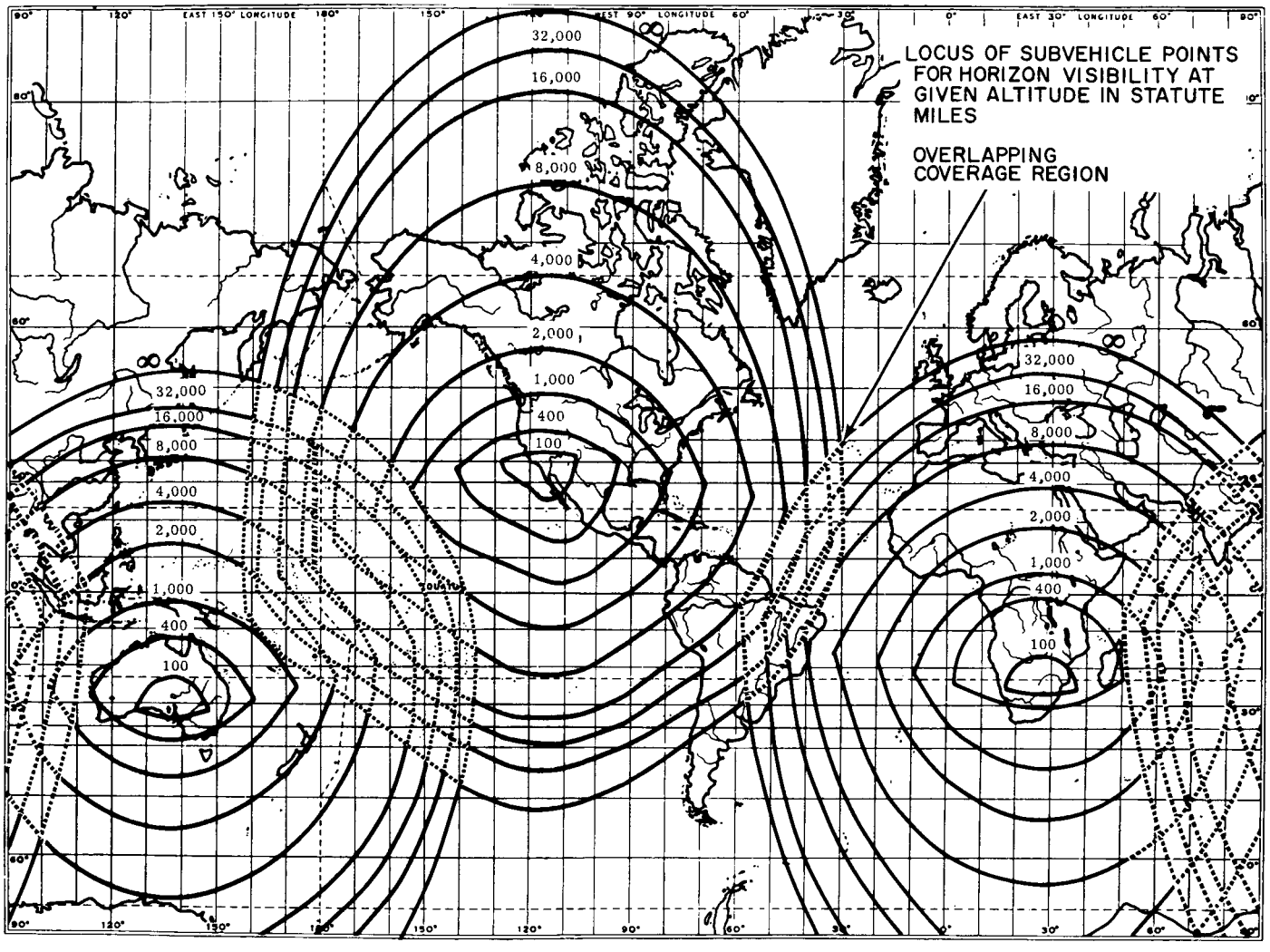


Fig. 3. Station coverage for 85-ft polar-mount DSIF antennas (Goldstone, Woomera, and Johannesburg)

III. SYSTEM CAPABILITIES

In the charts and text in this Section, the code (I) after the year designates existing installed facilities, (A) designates authorized and funded projects, and (P) designates proposed but not yet funded projects. Particular station configurations will vary somewhat from site to site and are not described in this Memorandum. Such configurations are shown in applicable program documents.

A. Tracking Data

1. Angle Tracking

The automatic-angle-tracking systems used in the DSIF are of the simultaneous lobing type. The 85-ft Ha-Dec antenna has two maximum tracking-rate capabilities, 1.0 deg/sec and 0.03 deg/sec,depending on tracking-system bandwidth requirements. During the periods in which angle-tracking accuracy is most significant (e.g., when data for midcourse-maneuver computation and for initial ephemeris calculation are acquired), the strong signal levels available result in a root-mean-square (rms) angle-tracking error from 0.01 to 0.02 deg. The rms tracking error at receiver threshold increases to approximately 0.05 deg. Bias errors are also of this magnitude; however, results of star-tracking data have, for the most part, made possible the stripping out of these bias errors.

The 10-ft Az-El antenna has a maximum tracking-rate capability of 10 deg/sec. Angle errors during post-injection tracking are usually no greater than 0.1 deg rms. Angle data from all DSIF antennas are digitally encoded directly from the servo-positioning system and routed to the data-handling facility. Angle data as sent to the

Central Computer Facility are smoothed only by the noise bandwidth of the servo-tracking system.

2. Range Tracking

A ranging system is presently under development by JPL and is planned for operational use with a 2115/2295-Mc transponder. The system measures the time difference between two identical, separately generated, pseudo-random noise codes (one generated at the transmitter for modulation and the other at the receiver for correlation detection) to represent range. The spacecraft transponder utilizes the same correlation technique to reconstruct the code sequence in order to improve the signal-to-noise ratio before retransmission to Earth. Unambiguous presentation of spacecraft range at interplanetary distances is planned, with a range resolution equivalent to 0.1 μsec. The ranging system for the DSS's is planned for use with 10-kw transmitters, programmed for installation at each site. Ranging at the mobile stations will be used with a 25-w transmitter. Considering the same system-communication parameters, the ranging-system distance capability surpasses the CW (carrier) threshold capability because of the possibility of using narrower loop bandwidths in the ranging locked loop than is possible in the carrier locked loop. DSIF ranging capability at all stations is planned for March 1963 (P). An advanced-development prototype of a ranging system is expected to be in operation at Goldstone in July 1962 (I).

The general mode of operation for the ranging system will be to use a short period to establish range-lock, and then to remove range modulation and to count doppler cycles to maintain the range tally. At the present time, telemetry and command systems will be inoperative during active ranging measurements.

3. Doppler

One-way and two-way radial doppler measurement capability is to be included in the DSIF. Two-way doppler requires a ground transmitter in the vicinity of the receiver to achieve frequency control by a single exciter. The distance at which the DSIF stations can obtain doppler data is, of course, dependent on the sensitivity of the spacecraft receiver and power output of the spacecraft transponder; if the carrier can be locked, doppler can be made available. (See Appendix for a discussion of the communications-range capability.)

The accuracy of one-way doppler data is limited because of unknown spacecraft oscillator drift. In the two-way system, the frequency control is maintained by the ground-transmitter exciter and is precisely known. One-way doppler is extracted at an equivalent 31-Mc carrier frequency; two-way doppler is extracted at an equivalent 32-Mc carrier frequency. Two-way precision doppler is available with the shift at the RF carrier frequency (960 Mc). Because of the increasing percentage effects of systematic errors (e.g., refraction), it appears that 0.17 m/sec rms is the practical radial-velocity measurement accuracy at present (see Table 2).

Table 2. DSIF programmed doppler capability

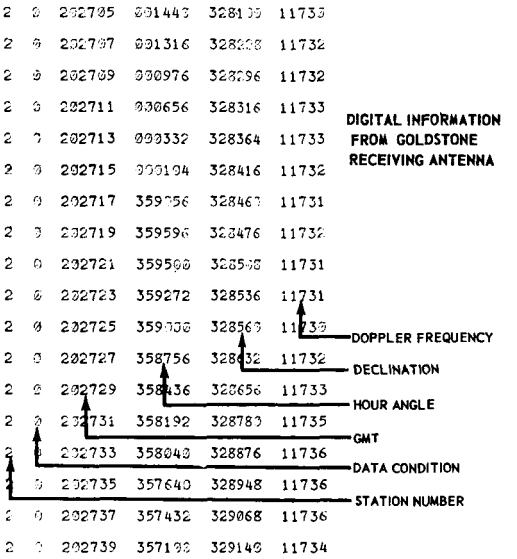
Type	Equipment resolution m/sec	Year operational in DSIF			Mobile station
		GS	W	J	
One-way	10	1960 (I)	1960 (A)	1961 (A)	1960 (I)
Two-way	5	1960 (A)	1962 (P)	1962 (P)	1960 (A)
One-way precision	0.34	1961 (A)	1962 (P)	1962 (P)	1961 (A)
Two-way precision	0.17	1961 (A)	1962 (P)	1962 (P)	1961 (A)

Cumulative doppler counts can be supplied to eliminate round-off error.

4. Data Handling

Automatic data-handling equipment is presently operational at Goldstone, Woomera, and the mobile tracking station; it will be operational at all DSIF stations in 1961. Data format is such that 120 characters can be printed out per line. The system is presently capable of tape-punching 60 characters per second; however, the intersite teletype communication system can transmit a maximum of 6 characters per second. The present system transmits doppler data, data condition, station identification, time, and two angles every 10 sec (see Fig. 4a). Sample rates from one per second to one per 90 min are available. When the ranging capability is added to the DSIF, range will be included in the teletype format (see Fig. 4b).

Transfer of telemetering data from overseas DSS's to JPL may be accomplished in several ways, depending on the urgency of its use. The normal method will be to airmail the telemetry tapes to JPL, with the attendant delay of approximately 72 hr. Other more rapid methods include use of the teletype system after the completion of the particular DSS tracking mission, and use of commercial radio-telephone facilities. At the present time, local reduction and re-transcription of data is necessary when teletype or radio-telephone methods are used.



a. Present format

b. With ranging

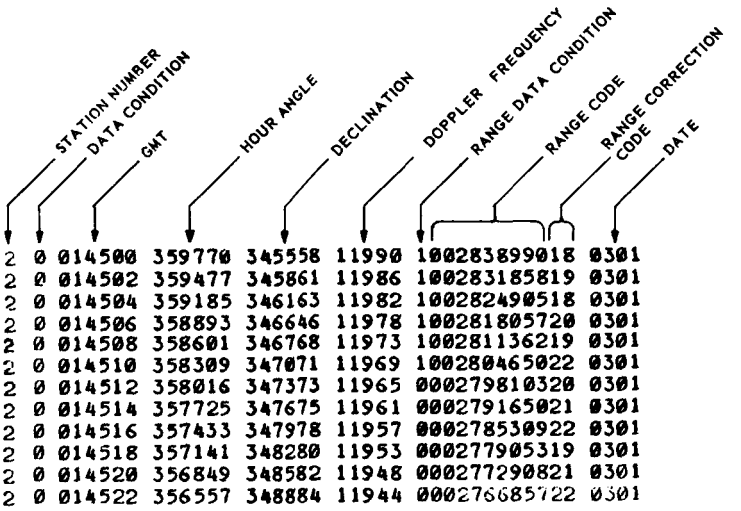


Fig. 4. Teletype format

B. Communications Data

1. Telemetry

The present ground-telemetering system provides information bandwidths of 3.5 kc and is designed to accept FM/PM modulation. A wide-bandwidth (1-3 Mc) detection capability is presently under consideration and is planned for integration into the DSIF as part of the 2295-Mc receiver. In most instances, the method of subcarrier detection and the logical design of the ground-station telemetering system will be dictated by the requirements of a particular spaceprobe experiment, and will most likely vary somewhat from experiment to experiment. As a standard capability, however, IRIG subcarrier channels 1 through 3 are presently incorporated in the DSIF. Goldstone and the mobile station have available IRIG channels 4 through 7 also. Phase-lock subcarrier detection techniques are utilized.

2. Command

To provide for the interrogation or command of a space probe, an initial command capability consisting of three audiofrequency tones will be provided in the 1961-62 (A) period. Future command requirements appear to favor a digital technique, and this digital command system will probably be introduced to the DSIF in 1962 (P). Again, as in telemetering, command capability is closely related to the requirements of individual space-probe experiments, and in most instances the command unit–DSIF interface will consist of a transmitter phase-modulator.

3. Recording Equipment

The recording equipment installed or programmed for installation at each DSIF site is designed to allow recording of a variety of signals, both spacecraft

and locally generated. The types of available equipment are shown in Table 3. Signal-conditioning equipment of various types is also provided.

Table 3. DSIF programmed recording equipment

Location	Year operational in DSIF					
	Direct writing (8-channel)	Photographic oscillograph (36-channel)	Photographic oscillograph (14-channel)	Tape recorder (CEC-752 type)[a]	Video tape recorder (FR-700 type)	Digital recorder
GS	Jan 1960[b] (I)	Dec 1960[c] (I)	Dec 1960[d] (I)	Dec 1960[e] (I)	Jul 1961 (A)	Jan 1962 (P)
W			Dec 1960 (I)	Dec 1960[e] (I)	Jan 1962 (P)	Jan 1963 (P)
J			Apr 1961 (A)	Apr 1961[e] (I)	Jan 1962 (P)	Jan 1963 (P)
Mobile station		Dec 1960 (I)		Dec 1960 (I)		

[a]May be frequency-multiplexed.

[b]Available at transmitter and receiver sites.

[c]Available at transmitter site only.

[d]Available at receiver site only.

[e]Two each per site.

The timing system available at each site is stable over a one-day period to 5 parts in 10^{10}. Local-time readout is synchronized to WWV to at least 10 ms, and, at Goldstone, WWV synchronization is usually better than 1 ms. Time readout is available locally in digital and visual display, and serial coded time is available at 1-sec, 1-min, or 1-hr readout intervals. Maser timing and frequency control systems are under consideration for use in the DSIF in the 1963-64 period.

4. Special-Purpose Equipment

The major part of the DSIF equipment is or will be standardized for the purpose of reducing spares costs; insuring equalized high performance; and allowing standard training, maintenance, checkout, and countdown procedures to be utilized. Such standardized equipment is designated as Goldstone Duplicate Standard (GSDS). Certain situations exist, however, in which fund limitations and/or program and schedule requirements preclude a GSDS designation; such equipment may be peculiar to any of the DSS's, depending on the need of a particular program.

In general, special-purpose communications equipment will be limited to modulation, demodulation, and data-handling equipment specifically required to satisfy a particular program need. Funding and engineering of this special-purpose equipment shall be handled as part of, and will be the responsibility of, the program using it; however, spares requirements, interface configurations, operational procedures, etc., must be coordinated through the DSIF. Facility negotiations and schedules will be a responsibility of the DSIF. Operation of specialized equipment will be decided by mutual agreement. Some of this specialized equipment, if its use has shown it to be efficient and reliable and it appears to be versatile in its application to many programs, may be integrated into the DSIF as GSDS.

5. Intersite Communications

A NASA-operated communication net linking the DSIF stations is utilized for data transfer and for operational control of the DSIF by JPL. The capability that will exist in the 1960-62 (A) period is shown in Fig. 5.

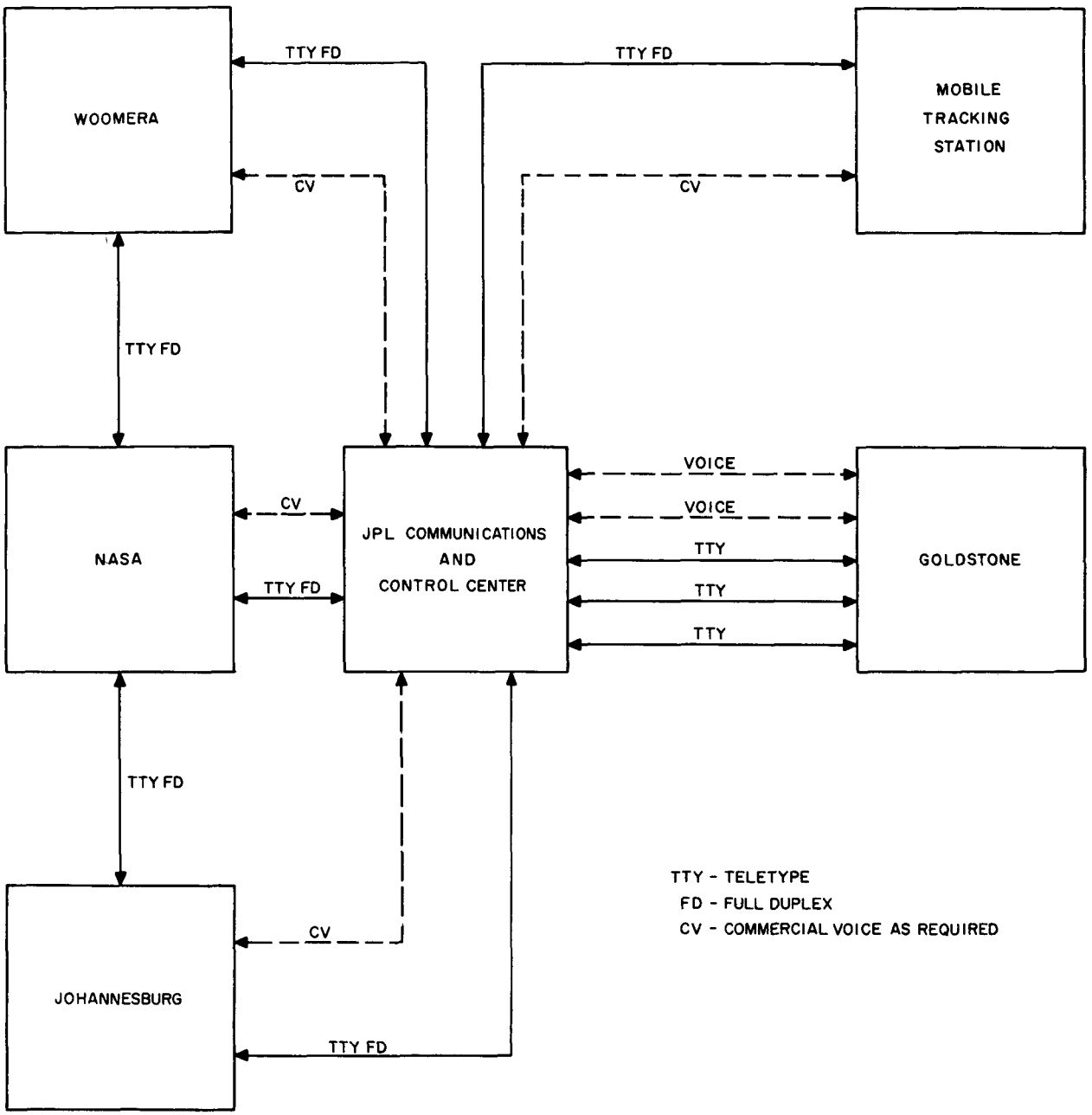


Figure 5. Communications net linking the DSIF stations

A high-frequency system linking the DSIF stations is under consideration for operational use in the 1963-65 (P) period. Bandwidth capability for this system is planned to be in excess of 3 kc. Communications reliability of 85 to 90% is anticipated.

C. Communications Systems

1. DSIF Frequencies

Frequencies assigned to JPL for use on DSIF missions fall into two general categories: ground-transmitter frequencies and spacecraft-transmitter frequencies. Table 4 shows the allocated and tentatively allocated JPL space-mission frequencies.

Table 4. JPL space-mission frequencies

Frequency, Mc	Year operational in DSIF[a]	Use
890	1960-63[b]	Transmitter frequency for DSIF equipment (25 w to 10 kw). Receiver frequency for spacecraft equipment.
960	1960-63[b]	Receiver frequency for DSIF equipment. Transmitter frequency for spacecraft equipment (1/4 to 100 w).
2115 ± 5	1963-	Transmitter frequency for DSIF equipment (25 w to 100 kw). Receiver frequency for spacecraft equipment. The exact frequencies have not yet been chosen, but are expected to be from 6 to 10% lower than the assigned 2290 to 2300-Mc band. (Six to ten per cent higher frequency is also under consideration.)
2295 ± 5	1963-	Receiver frequency for DSIF equipment. Transmitter frequency for spacecraft equipment (to 1 kw).

[a]Operational capability of DSIF may not include all DSS's at the earlier dates listed.

[b]Use of the 890 to 960-Mc band will be terminated in January 1963.

A general receiving capability is under consideration for the purpose of receiving and recording telemetry data in the 20-Mc to 10-kMc region. Initially, it is planned to develop and/or incorporate broadband feeds, tunable receivers, wideband-telemetry detection channels, and wide-bandwidth recording systems into the DSIF. This capability is being considered so that the DSIF may react efficiently to requirements for tracking space probes other than those under JPL-mission cognizance.

2. DSIF Transmitters

Transmitter capability is incorporated in the DSIF for the purpose of providing two-way doppler data and ranging data and for command of the spacecraft. Depending on the particular mission, power outputs from 25 w to 10 kw are planned. In general, the transmitters will have a phase-modulation capability and will be excited with a voltage-controlled oscillator operated in the 30-Mc region. In some instances, diplexed operation, with a receiver operating at a different frequency, will be employed. Presently under consideration is a 100-kw-transmitter installation for the DSIF. Table 5 indicates the present and future planned transmitter capability.

Table 5. DSIF programmed transmitter capabilities

Frequency Mc	Power output	GS	Year operational in DSIF		Mobile station	Antenna
			W	J		
890	25 w				Dec 1960 (I)	10-ft Az-El
890	200 w [a]	Jun 1961[b] (I)				85-ft Az-El
890/960[c]	10 kw	Dec 1960 (I)				85-ft Az-El
890	200 w[a]		Aug [b] 1962	Aug [b] 1962		85-ft Ha-Dec
2115 ± 5	10 kw	Dec 1960 (I)				85-ft Az-El
2115 ± 5	25 200 w[e]				Jan 1963 (P)	10-ft Az-El
2115 ± 5	10 kw	Jul 1962[b] (P)	Jan 1963[b] (P)[d]	Jan 1963[b] (P)[d]		85-ft Ha-Dec
2115 ± 5	100 kw	1963 (P)	1965 (P)	1965 (P)		85-ft Az-El

[a] Either 10-kw, 890-Mc transmitter will be installed and operated with 200-w output, or separate 200-w power amplifier will be provided.

[b] Diplexed.

[c] Transmitter will be utilized for interstation Moon-bounce communication.

[d] Initially, the overseas 10-kw transmitters will be installed on the 85-ft polar-mount receiving antenna; they will be moved to the 85-ft Az-El antenna when it is installed.

[e] Actual power not decided.

3. DSIF Receivers

The DSIF stations incorporate extremely sensitive and stable receivers which are designed for the purpose of tracking the received RF carrier in phase, and for amplitude and phase-sensitive detection of the sidebands. The various receivers listed in Table 6 are comprised of a low-noise preselector/mixer, carrier and sideband IF amplifiers, detectors, and a voltage-controlled local oscillator, the combination comprising a double superheterodyne receiver, which is locked in phase to the received signal. Doppler data are derived from the local oscillator, telemetry data from either the phase error in the tracking loop or from a separate detection channel, and angle data from separate angle-error detection channels.

Minor modifications of the receiver will be necessary to incorporate the ranging system. In general, correlation detection of the range code will be accomplished at the first mixer, with the bulk of the ranging equipment being separate from the receiver.

Table 6. DSIF programmed receiver capabilities

Frequency Mc[a]	Year operational in DSIF						Mobile station	Receiver-system excess noise °K	Type	Bandwidth[b]	
	Goldstone		Woomera		Johannesburg					Carrier loop noise[c] cps	Telemetry channel information
	1	2	1	2	1	2					
960	Dec 1960(I)	May 1961(A)	Dec 1960(I)		May 1961(A)		Dec 1960(I)	1430	Track	20-250	0-3.5 kc
960	Jan 1962(A)	Jan 1962(A)	Jan 1962(P)		Jan 1962(P)			220/70[d]	Track	20-250	0-5 kc
2295 ± 5	Jul 1962(P)	Jan 1963(P)	Jan 1963(P)	Oct 1963(P)	Jan 1963(P)	Oct 1963(P)		235/50[e]	Track	3-250	0-1 Mc
2295 ± 5							Jan 1963(P)	1000	Track	20-250	0-1 Mc
2295 ± 5	Jul 1964(P)		Dec 1966(P)		Dec 1966(P)			20[f]	Listen	3-250	0-1 Mc

[a] In general, the receivers listed are capable of operation within several megacycles of the nominal center frequency by replacing a series of quartz crystals within the receiver system.

[b] The ranging system requires preselector and mixer bandwidths in excess of 5 Mc.

[c] Phase-lock loop-noise bandwidth is a function of the received signal level; hence, the frequency tracking-rate capability is a function of received signal level. The minimum bandwidths are limited because of the inherent phase instability of quartz crystals used in the communication system.

[d] A nominal 150°K excess-noise parametric amplifier will be installed at the Goldstone transmitter site and at the overseas DSS's; a 40°K excess-noise maser amplifier will be installed at the Goldstone receiver site.

[e] A nominal 200°K excess-noise parametric amplifier will be provided for receiver No. 1 and a nominal 30°K excess-noise maser amplifier will be provided for receiver No. 2. Diplexing may increase maser system temperature to approximately 100°K.

[f] Complete system excess-noise temperature, using 250-ft antenna (design goal).

4. DSIF Antennas and Feeds

a. Antenna temperature. Figure 6 shows antenna-temperature contours vs pointing angles recorded for the Goldstone 85-ft polar antenna at 960 Mc, using the sum channel output of a circularly polarized, simultaneous lobing tracking feed. The temperatures were recorded at the output of a feedline whose attenuation contributed approximately 45°K excess-noise temperature. A Dicke-type radiometer was used in this measurement. Similar data will be available from the Woomera and Johannesburg Deep Space Stations in 1961. DSIF temperature profiles will be available for 2290 to 2300 Mc in 1962. At 960 Mc, estimated Moon brightness temperatures vary between 210 and 250°K . The effective excess-noise temperature of the Moon depends on the beamwidth of the receiving antenna.

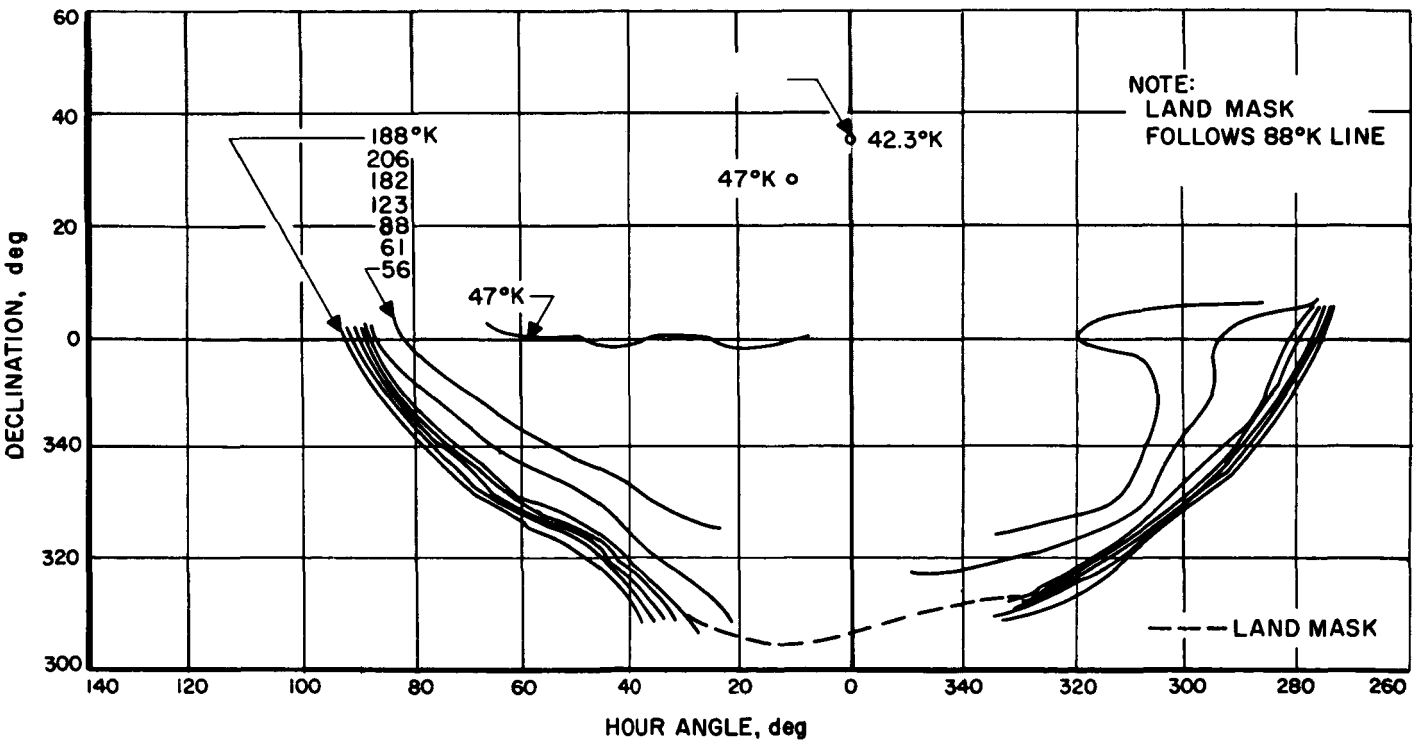


Figure 6. Goldstone antenna-temperature contours vs pointing angles recorded for the 85-ft polar antenna at 960 Mc

b. DSIF antenna reflectors. Antenna reflectors installed or programmed for installation in the DSIF are shown in Table 7.

Table 7. DSIF programmed antenna reflectors

Pointing[c] accuracy deg	Diameter ft	Type	Maximum angular rate deg/sec	Year operational in DSIF			
				GS	W	J	Mobile station
0.05	10	Az-El	20				Dec 1960 (I)
0.01	85	Ha-Dec	1	Jan 1960 (I)	Dec 1960 (I)	Apr 1961 (A)	
0.01	85	Az-El	2	May 1960 (I)	Dec 1963 (P)	Dec 1963 (P)	
0.02[a]	200-300	—[b]	0.2-0.5[a]	Dec 1963 (P)	Dec 1966 (P)	Dec 1966 (P)	

[a] Design goal.

[b] Not determined.

[c] The capability of pointing the radio beam in a specified direction within a specified peak error is defined as the pointing accuracy.

c. DSIF antenna feeds. The antenna feeds listed in Table 8 are planned for specific program support. As a general rule, tracking antennas are circularly polarized, transmitter antennas are circularly polarized, and spacecraft antennas are linearly polarized. Tracking feeds utilized are exclusively of the simultaneous lobing type.

d. Typical DSIF system. A typical DSIF system embodying all of the capabilities discussed above is shown in Fig. 7.

Table 8. DSIF programmed feed capability

Frequency Mc	Output power	Type	Gain[a]	Reflector diameter ft	Feed-line loss db[b]	Est. noise °K[c]	Polarization	Approx. beam-width deg	Year operational in DSIF			
									GS	W	J	Mobile station
960/890	200 w[d]	Track Trans.	43.5/43	85	0.7	80	Right Circ.	1.0	Jan 1960 (I)	Nov 1960 (I)	Apr 1961 (A)	
960/890	25 w[d]	Track Trans.	22.5/22	10	0.7	-	Right Circ.	9.0				Dec 1960 (I)
960/890	10 kw	Listen Trans.	45.8/45	85	0.4	60	Right Circ.	0.9	Aug 1962 (A)			
960/890	200 w	Listen Trans.	45.8/45	85	0.2	60	Linear[e]	0.85	Jan 1962 (A)	Aug 1962 (P)	Aug 1962 (P)	
2295 ± 5/ 2115 ± 5	10 kw[d]	Track Trans.	51.8/51	85	0.1	50	Right Circ.	0.4	Aug 1962 (P)	Jan 1963 (P)	Jan 1963 (P)	
2295 ± 5/ 2115 ± 5	10 kw	Listen Trans.	52.8/52	85	0.4	-	Linear[e]	0.38	Aug 1962 (P)			
2295 ± 5/ 2115 ± 5	25 w[d]	Track Trans.	33/32	10	0.5	-	Right Circ.	3.0				Jan 1963 (P)
2115 ± 5	100 kw	Trans.	51	85	0.4	-	Right Circ.	0.4	Jan 1963 (P)			
2115 ± 5	100 kw	Trans.	62	200-300	0.2	-	Right Circ.	0.13	Dec 1964 (P)	Dec 1966 (P)	Dec 1966 (P)	
2295 ± 5	-	Track	61	200-300	0.1	15	Right Circ.	0.15	Dec 1964 (P)	Dec 1966 (P)	Dec 1966 (P)	

[a]Gain is in decibels above isotropic radiator of matching polarization. Dual-frequency, circularly polarized feeds may have as much as 6-db ellipticity at the transmitting frequency and as much as 3-db ellipticity at the receiving frequency.

[b]Indicated loss is included in antenna gain.

[c]Includes excess noise due to losses in feed lines and antenna temperature at zenith with 0°K sky temperature.

[d]Diplexed. Diplexer loss is approximately 0.2 to 0.3 db in addition to that indicated.

[e]Rotatable.

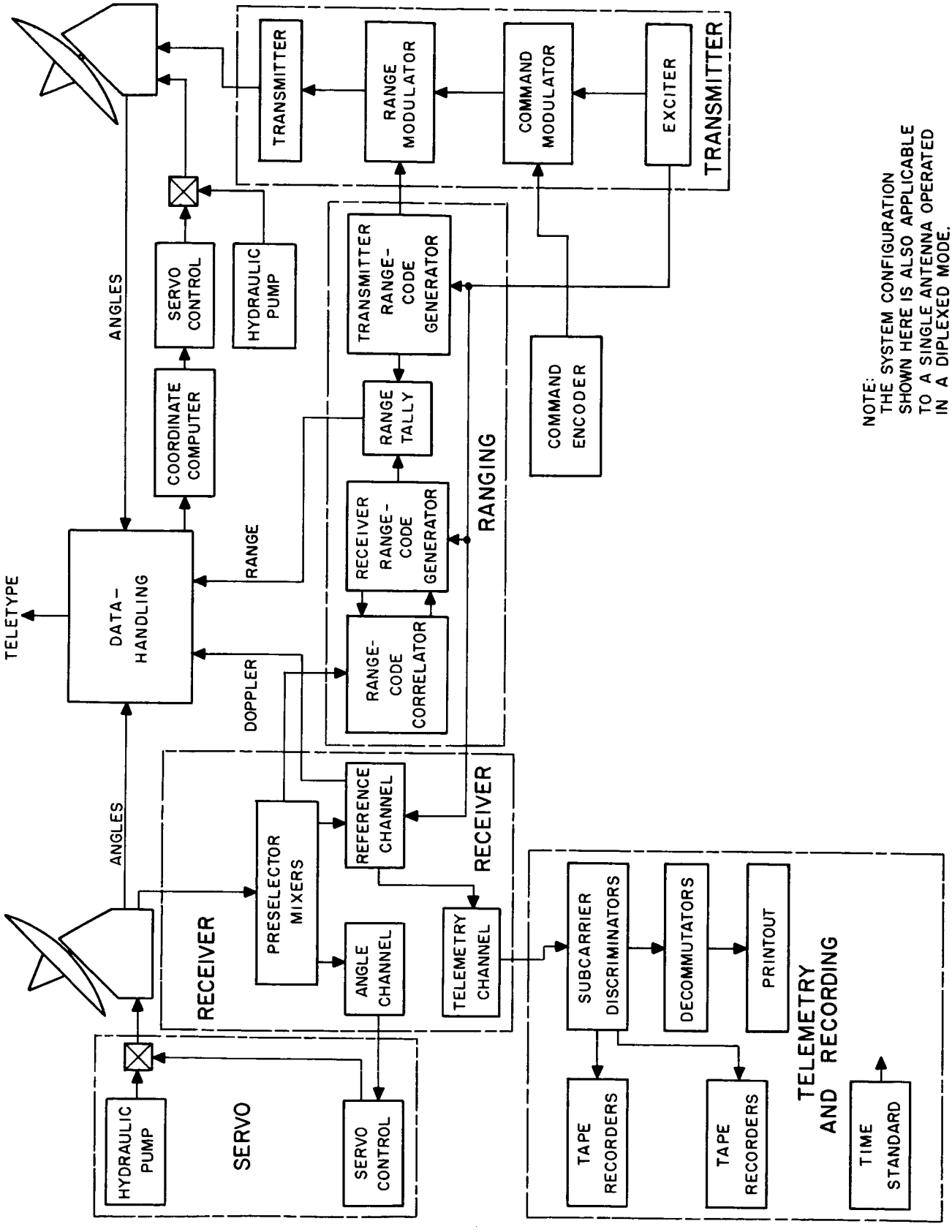


Figure 7. Typical deep space tracking station block diagram

5. DSIF Acquisition Procedures

DSIF spacecraft-acquisition requirements can be separated into the following modes: pointing, frequency, and code acquisition, or combinations of them. The requirement for continuity of data from the spacecraft necessitates that acquisition be made as promptly as possible; to this end, the DSIF provides automatic scan equipment in the three modes to minimize acquisition time. However, certain minimum time requirements still exist which may affect the results of spacecraft experiments:

a. Angle. Pointing information is usually provided for a tracking station; however, it is still necessary to search the area about which the probe position is predicted to be. Supplied ephemeris data are usually accurate to within a degree; however, as noted below, the combined requirement for both angle and frequency search may necessitate several minutes for complete acquisition.

b. One-way doppler. Lock in this mode can usually be achieved in 1 to 2 min. A priori information as to the expected received frequency considerably reduces the acquisition time to lock to the carrier. It is usually necessary, in any case, to be at least 3 to 6 db above threshold to establish carrier lock. Care must be exercised to avoid reference-channel phase lock on the subcarrier sidebands.

c. Two-way doppler. Two-way radio-frequency lock on a spacecraft transponder requires that the ground receiver first be locked on the spacecraft transmitter; then the ground-transmitter frequency is swept through the spacecraft-receiver frequency. The spacecraft receiver then acquires and switches from internal frequency control of the spacecraft transmitter to ground-transmitter frequency control, which then requires relocking of the ground receiver to the spacecraft transmitter. Periods involved could be in excess of 10 min.

d. Ranging. This is similar to two-way doppler; however, there is the additional complexity of acquiring range-code lock. Periods involved could be in excess of 15 min.

e. Telemetry subcarrier. The acquisition time of subcarrier channels is usually dependent on the system used. In general, once the carrier has been acquired, the subcarrier acquisition and synchronization (if digital) will take several minutes.

D. Testing and Checkout

At the present time, approximately 10 hr are required to ready a tracking station to support a tracking mission. All checkout, calibration, and testing are performed manually and much data reduction and interpretation is necessary before the station is adjudged satisfactory.

A program is underway to automate many of the procedures now performed manually, and it is estimated that the total time necessary to ready the station will be less than one hour. Included in this automatic equipment will be go–no-go indicators, fault-locating indicators, automatic-calibration equipment, and checkout sequencers. It is expected that the addition of this equipment will materially increase the operational reliability of the station and will enable the tracking stations to participate in a much higher percentage of total tracking hours.

IV. DSIF MISSION SCHEDULES

The existing facilities and programmed expansion of the DSIF are expected to provide adequate tracking and communications capability for the lunar and planetary programs, for which JPL is responsible, during the next five years.

In general, it is expected that any one tracking station can, as a maximum, track 70% of the time, which leaves 30% of the time for maintenance. However, it is doubtful that this tracking percentage can be maintained during the next five years, when one considers the time required for modification or up-dating the tracking stations and the time required to change tracking feeds and equipment necessary to track other experiments within a 24-hr tracking period.

The types of space explorations to be supported include 24-hr satellites, lunar probes, planetary probes, and extra-ecliptic probes. As indicated previously, the Goldstone Station will also be utilized for research and development studies; it is expected that approximately half of the Goldstone activity will be directed to this end. Also, it is expected that about 5% of the Woomera and Johannesburg schedule will be devoted to local research and development studies.

The tracking and communications scheduling requirements vary greatly, depending on the type of mission to be supported. A few examples of the requirements for specific missions are shown below.

1. High-density tracking requirements for several days
    a. Photographing lunar or planetary surfaces during encounter
    b. Obtaining trajectory data for midcourse maneuvers
2. Low-density tracking requirements for several months or years
    a. Deep-space ranging experiments for refinements of the astronomical unit
    b. Particle or radiation experiments in deep space (using data storage)

3. High-density tracking requirements for several weeks
    a. Mobile lunar explorations
    b. Dual-vehicle (satellite and soft-lander) planetary exploration
4. High-density tracking requirements for several months
    a. Lunar mapping, using an orbital camera
    b. Measurements of lunar or planetary surfaces by means of soft-landed capsules

APPENDIX

Communications Capabilities of the Deep Space Instrumentation Facility

The figures shown in this Appendix are representative of the systems capability of the DSIF in the period 1961-66. The spacecraft communications capability shown is based on existing and planned equipment to be utilized in JPL space missions. The combinations shown are also typical of those planned and are given for the Goldstone site capability.

The following assumptions are made:

1. A 6-db loss pad is included to compensate for various small losses and inaccuracies in the assumed parameters.
2. Sky temperature is assumed to be 0°K.
3. Total transmitter power is divided equally between the carrier and the sidebands; therefore, the value of P_T used in Fig. A-1, A-2, and A-3 is 3 db less than that shown in Table A-1.
4. The maximum tracking range is limited by the minimum possible loop-noise bandwidth of the carrier phase-locked system. Realizable values for this parameter are as follows:

Year	Spacecraft Receiver	Ground Receiver
1961	100 cps	20 cps
1963	20 cps	3 cps
1965	10 cps	3 cps

Table A-1. Communications parameters[a-1]

Year	Frequency Mc	P_T w	G_T db	T °K	G_R db
Spacecraft to Earth (see Fig. A-1)					
1961	960	3	18	1500	44
1962	960	25	18	300	44
1963-64	2295	250	30	100	50
1965-66	2295	250	35	20	62
Earth to spacecraft (see Fig. A-2 and A-3)					
1961-62	890	10^4	44	2600	18/0[a-2]
1963-64	2115	10^4	50	1000	30/0[a-2]
1965-66	2115	10^5	61	400	35/0[a-2]

[a-1] Values shown are nominal.

[a-2] Values are shown in Fig. A-3 for an isotropic receiving antenna on the spacecraft.

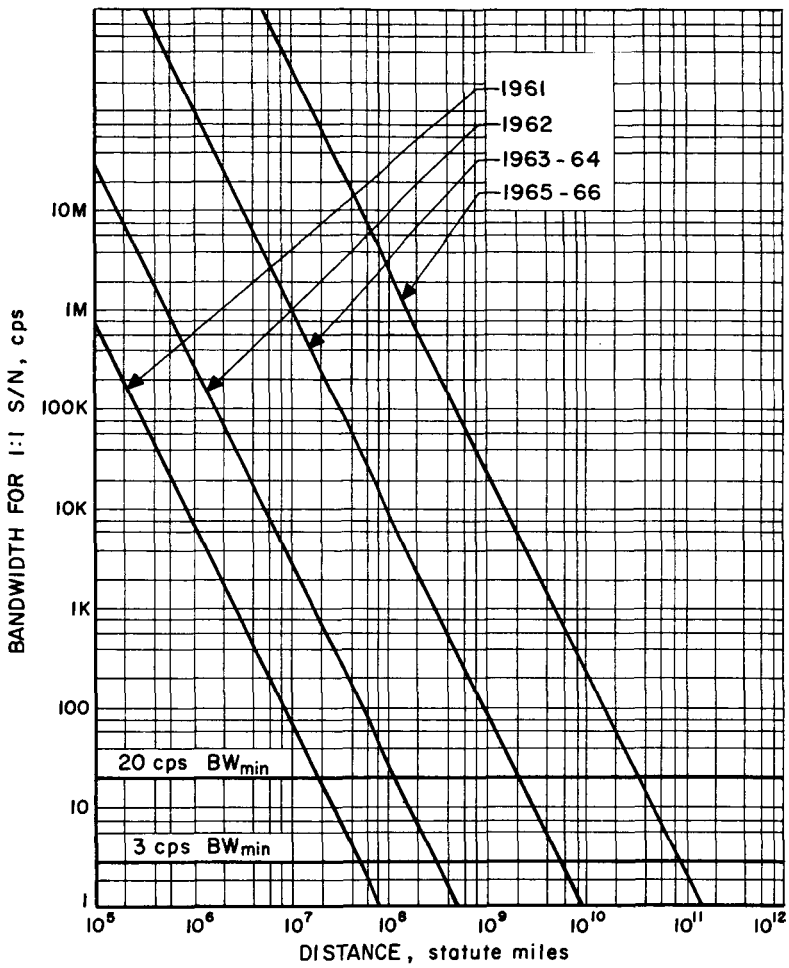


Fig. A-1. Spacecraft-to-Earth communications capabilities

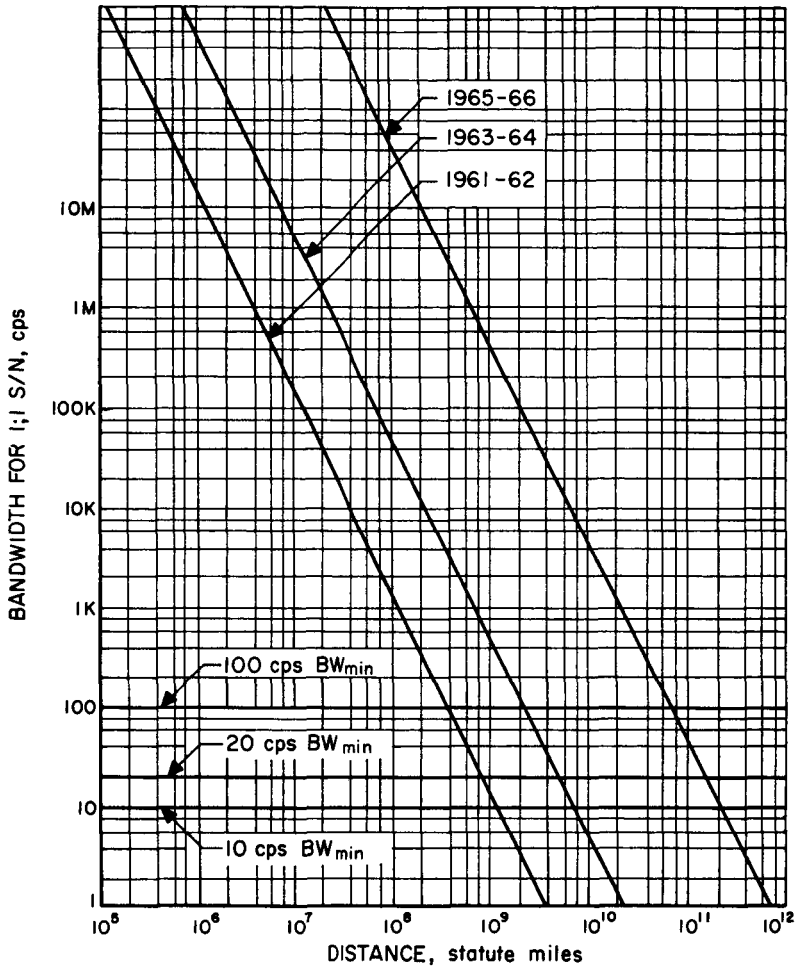


Fig. A-2. Earth-to-spacecraft communications capabilities, spacecraft directional antenna

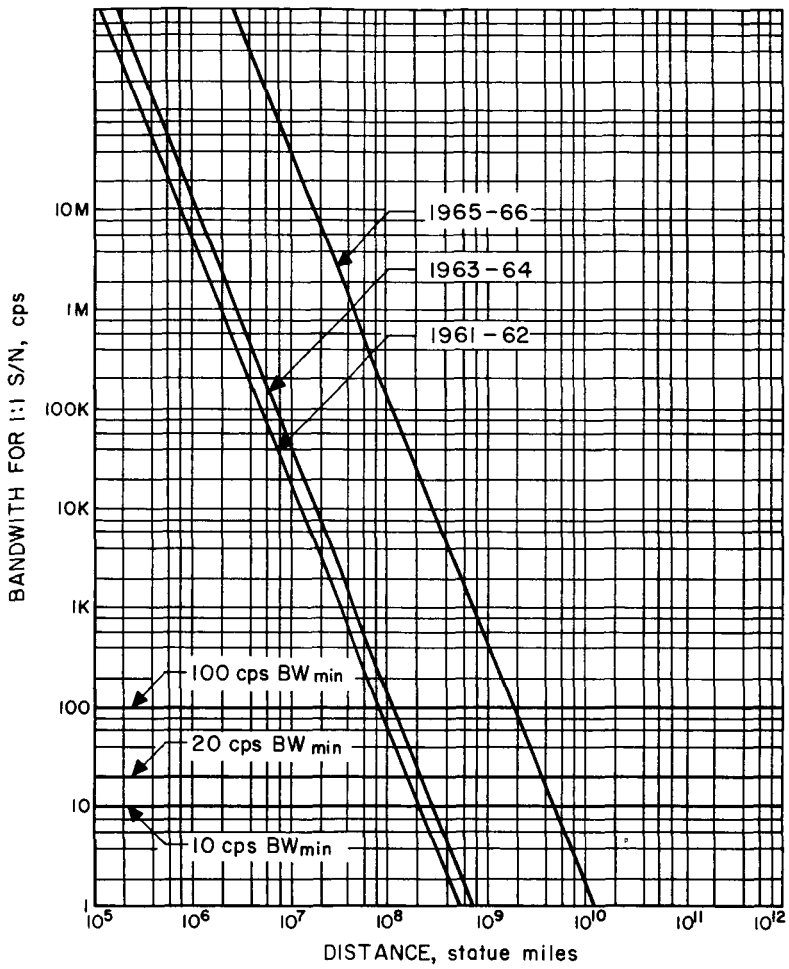


Fig. A-3. Earth-to-spacecraft communications capabilities, spacecraft omnidirectional antenna

The calculations on which Fig. A-1, A-2, and A-3 are based are derived from the familiar line-of-sight transmission equation

$$P_R = P_T + G_T + G_R - L_{FS} - L_P \tag{1}$$

where

P_R = power at the receiver input, dbm

P_T = transmitter power output, dbm

G_T = transmitter antenna gain, db over isotropic

G_R = receiver antenna gain, db over isotropic

L_{FS} = loss between isotropic radiators in free space, db

L_P = loss pad to account for various system losses, db

The loss between isotropic radiators in free space is given by

$$L_{FS} = 36.6 + 20 \log D + 20 \log f \tag{2}$$

where

D = distance, statute miles

f = frequency, Mc

Thermal noise power is related to source temperature and bandwidth by the following equation:

$$P_N = KTB \tag{3}$$

where

P_N = noise power, mw

K = $1.38 \times 10^{-20} \frac{(\text{mw x sec})}{^\circ\text{K}}$ (Boltzmann's constant, -198.6 dbm)

T = receiver-system excess-noise temperature, °K

B = Bandwidth, cps

For a 1:1 signal-to-noise ratio,

$$P_R = P_N$$

Using Eq. (3), P_N may be expressed in dbm:

$$P_N = 10 \log k + 10 \log T + 10 \log B$$

$$P_N = -198.6 + 10 \log T + 10 \log B \tag{4}$$

To find maximum tracking range, Eq. (4) and (2) are substituted into Eq. (1), and D is solved for:

$$P_R = -198.6 + 10 \log T + 10 \log B$$

$$= P_T + G_T + G_R - 36.6 - 20 \log D - 20 \log f - L_P$$

$$20 \log D = P_T + G_T + G_R - 20 \log f - L_P - 10 \log T - 10 \log B + 162.0 \tag{5}$$

In evaluating various systems, assumptions are made for all parameters except D and B. Then B is varied, and Eq. (5) is solved for D. To simplify Eq. (5), a system gain G_S is defined:

$$G_S = P_T + G_T + G_R - 20 \log f - L_P - 10 \log T + 162.0 \tag{6}$$

Equation (5) then becomes:

$$20 \log D = G_S - 10 \log B \tag{7}$$

Figures A-1, A-2, and A-3 show tracking distance vs bandwidth for a 1:1 signal-to-noise ratio. For ease in using the figures, it should be noted that a tenfold change in bandwidth results in a 10-db change in signal-to-noise ratio, whereas a tenfold change in distance results in a 20-db change in signal-to-noise ratio.

Distances from Earth to various astronomical objects are given in Table A-2.

Table A-2. Distances from Earth to various astronomical objects

Object	Distance, statute miles	
	Minimum	Maximum
Moon	2.2×10^5	2.5×10^5
Venus	2.4×10^7	1.63×10^8
Mars	3.7×10^7	2.5×10^8
Mercury	6.2×10^7	1.39×10^8
Jupiter	3.7×10^8	6.0×10^8
Saturn	7.5×10^8	1.03×10^9
Pluto	2.7×10^9	4.7×10^9
Alpha Centauri	2.6×10^{13}	–